

Claims

- [c1] A plasma source comprising:
 - a cathode assembly comprising an inner cathode section and an outer cathode section;
 - an anode that is positioned adjacent to the outer cathode section and forming a gap there between;
 - a first power supply that generates a first electric field across the gap, the first electric field ionizing a volume of feed gas that is located in the gap, thereby generating an initial plasma; and
 - a second power supply that generates a second electric field proximate to the inner cathode section, the second electric field super-ionizing the initial plasma to generate a plasma comprising a higher density of ions than the initial plasma.
- [c2] The plasma source of claim 1 further comprising a second anode that is positioned adjacent to the inner cathode section, the second power supply generating the second electric field between the inner cathode section and the second anode.
- [c3] The plasma source of claim 1 wherein the first and the second power supplies are chosen from the group comprising a pulsed DC power supply, an AC power supply, a DC power supply, and a RF power supply.
- [c4] The plasma source of claim 1 wherein the first power supply further generates a third electric field across the gap, the third electric field super-ionizing the initial plasma that is located in the gap.
- [c5] The plasma source of claim 1 further comprising a third power supply that generates a third electric field across the gap, the third electric field super-ionizing the initial plasma that is located in the gap.
- [c6] The plasma source of claim 1 wherein the first and the second power supplies comprise a single power supply that generates the first and the second electric fields.
- [c7] The plasma source of claim 1 wherein the first and the second electric fields are

chosen from the group comprising a static electric field, a pulsed electric field, a quasi-static electric field, and an alternating electric field.

- [c8] The plasma source of claim 1 wherein the initial plasma comprises a weakly-ionized plasma.
- [c9] The plasma source of claim 1 wherein the plasma comprising the higher density of ions comprises a strongly-ionized plasma.
- [c10] The plasma source of claim 1 wherein the super-ionizing the initial plasma comprises converting at least seventy-five percent of neutral atoms in the initial plasma to ions.
- [c11] The plasma source of claim 1 wherein the first electric field generates excited atoms in the initial plasma and generates secondary electrons from the outer cathode section, the secondary electrons ionizing the excited atoms, thereby creating a plasma comprising a higher density of ions than the initial plasma.
- [c12] The plasma source of claim 1 further comprising a gas valve that controls the flow of feed gas so as to exchange the initial plasma with a second volume of feed gas as the first power supply generates the first electric field across the second volume of feed gas, thereby increasing an ion density of the plasma.
- [c13] The plasma source of claim 1 further comprising a gas valve that injects feed gas between the outer cathode section and the anode at a predetermined time.
- [c14] The plasma source of claim 1 wherein at least one of the first and the second power supplies generates the first and the second electric fields, respectively, with a constant power.
- [c15] The plasma source of claim 1 wherein at least one of the first and the second power supplies generates the first and the second electric fields, respectively, with a constant voltage.
- [c16] The plasma source of claim 1 wherein at least one of the first and the second power supplies generates the first and the second electric fields, respectively, with a constant current.

- [c17] The plasma source of claim 1 further comprising a magnet assembly that is positioned to generate a magnetic field proximate to at least one of the inner and the outer cathode sections, the magnetic field trapping electrons in at least one of the initial plasma and the plasma comprising the higher density of ions.
- [c18] The plasma source of claim 17 wherein the magnet assembly comprises a plurality of magnets that generate magnetic field lines that are substantially parallel to at least one of the inner and the outer cathode sections.
- [c19] The plasma source of claim 1 wherein at least one of the inner and the outer cathode sections comprises a target material that is used for sputtering.
- [c20] A method of generating a high-density plasma, the method comprising:
generating a first electric field across a gap between an anode and an outer cathode section, the first electric field ionizing a volume of feed gas that is located in the gap, thereby generating an initial plasma in the gap;
exchanging the initial plasma with a second volume of feed gas while applying the first electric field across the gap, thereby generating an additional plasma in the gap; and
generating a second electric field proximate to the inner cathode section, the second electric field super-ionizing the initial plasma, thereby generating a plasma comprising a higher density of ions than the initial plasma.
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[c21] The method of claim 20 wherein the generating the first electric field across the gap comprises generating excited atoms in the initial plasma and generating secondary electrons from the outer cathode section, the secondary electrons ionizing the excited atoms, thereby creating a plasma comprising a higher density of ions than the initial plasma.
- [c22] The method of claim 20 wherein the first and the second electric fields are chosen from the group comprising a static electric field, a quasi-static electric field, a pulsed electric field, and an alternating electric field.
- [c23] The method of claim 20 wherein the peak ion density of the initial plasma is between about 10^7 cm^{-3} and 10^{12} cm^{-3} .

- [c24] The method of claim 20 wherein the peak ion density of the plasma comprising the higher density of ions is greater than about 10^{12} cm^{-3} .
- [c25] The method of claim 20 wherein super-ionizing the initial plasma comprises converting at least seventy-five percent of neutral atoms in the initial plasma to ions.
- [c26] The method of claim 20 further comprising generating a magnetic field proximate to at least one of the inner and outer cathode sections, the magnetic field trapping electrons in at least one of the initial plasma and the plasma comprising the higher density of ions.
- [c27] The method of claim 26 wherein the magnetic field comprises magnetic field lines that are substantially parallel to at least one of the inner and the outer cathode sections.
- [c28] The method of claim 20 wherein the presence of the initial plasma reduces a probability of developing an electrical breakdown condition proximate to the inner cathode section as the second electric field is generated.
- [c29] The method of claim 20 further comprising exposing a substrate to the plasma comprising the higher density of ions, thereby etching a surface of the substrate.
- [c30] A segmented cathode assembly for generating a high-density plasma, the segmented cathode assembly comprising:
 - an inner cathode section;
 - an outer cathode section that surrounds the inner cathode section; and
 - a first anode that is positioned adjacent to the outer cathode section and forming a gap there between.
- [c31] The segmented cathode assembly of claim 30 further comprising a second anode that surrounds the inner cathode section.
- [c32] The segmented cathode assembly of claim 30 further comprising a magnet assembly that is positioned to generate a magnetic field proximate to at least one of the inner and the outer cathode sections.

- [c33] The segmented cathode assembly of claim 32 wherein the magnet assembly is rotatable.
- [c34] The segmented cathode assembly of claim 32 wherein the magnet assembly comprises a plurality of magnets that generate magnetic field lines that are substantially parallel to at least one of the inner and the outer cathode sections.
- [c35] The segmented cathode assembly of claim 30 wherein at least one of the inner and the outer cathode sections comprises a target material that is used for sputtering.
- [c36] The segmented cathode assembly of claim 30 further comprising at least one gas valve that injects feed gas into the gap at a predetermined time.
- [c37] The segmented cathode assembly of claim 31 further comprising at least one gas valve that injects feed gas between the inner cathode section and the second anode at a predetermined time.
- [c38] A method of generating a high-density plasma, the method comprising:
ionizing a volume of feed gas that is located in a gap between an anode and an outer cathode section to generate an initial plasma;
transporting the initial plasma proximate to an inner cathode section; and
super-ionizing the initial plasma that is located proximate to the inner cathode section, thereby generating a plasma comprising a higher density of ions than the initial plasma.
- [c39] The method of claim 38 wherein the ionizing a volume of feed gas comprises applying an electric field across the volume of feed gas.
- [c40] The method of claim 38 wherein the super-ionizing the initial plasma comprises applying an electric field across the initial plasma.
- [c41] The method of claim 38 wherein the peak ion density of the initial plasma is between about 10^7 cm^{-3} and 10^{12} cm^{-3} .
- [c42] The method of claim 38 wherein the peak ion density of the plasma comprising the higher density of ions is greater than about 10^{12} cm^{-3} .

- [c43] The method of claim 38 wherein the super-ionizing the initial plasma comprises converting at least seventy-five percent of neutral atoms in the initial plasma to ions.
- [c44] The method of claim 38 wherein the transporting the initial plasma proximate to the inner cathode section comprises exchanging the initial plasma with a second volume of feed gas.
- [c45] A plasma source comprising:
means for generating a first electric field across a gap between an anode and an outer cathode section, the first electric field ionizing a volume of feed gas that is located in the gap, thereby generating an initial plasma in the gap;
means for exchanging the initial plasma with a second volume of feed gas while applying the first electric field across the gap, thereby generating an additional plasma in the gap; and
means for generating a second electric field proximate to an inner cathode section, the second electric field super-ionizing the initial plasma, thereby generating a plasma comprising a higher density of ions than the initial plasma.
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- [c46] A plasma source comprising:
means for ionizing a volume of feed gas that is located in a gap between an anode and an outer cathode section to generate an initial plasma;
means for transporting the initial plasma proximate to an inner cathode section; and
means for super-ionizing the initial plasma that is located proximate to the inner cathode section, thereby generating a plasma comprising a higher density of ions than the initial plasma.